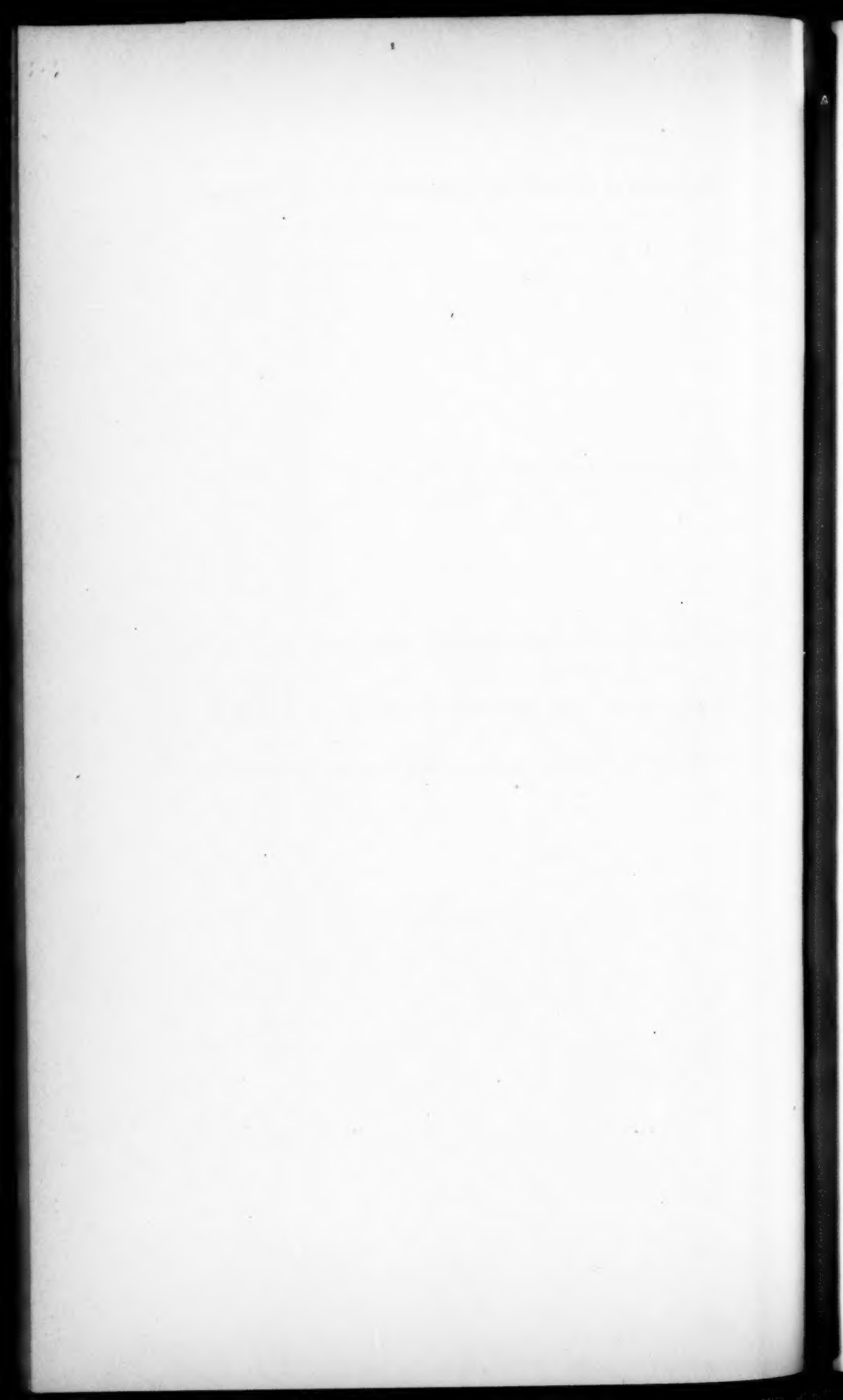## CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

A REVISION OF THE ATOMIC WEIGHT OF COBALT.

FIRST PAPER. — THE ANALYSIS OF COBALTOUS BROMIDE.

By Theodore William Richards and Gregory Paul Baxter.

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INTRODUCTION.

SIMULTANEOUSLY with the work described in the preceding paper, a similar investigation of cobalt was in progress. Earlier work upon this metal had led to results quite as incapable of ready interpretation as those concerning nickel; even very recent work upon the atomic weight of cobalt allows a range of much over a unit (from 58.78 to 60.1) as the possible field within which the truth may lie. Professor Clarke has given a full summary of all the available data upon this subject in his recent work * upon the Recalculation of the Atomic Weights, and for references and details the reader is referred to this useful volume. A chronological list is reprinted here merely to show how urgent is the need for further labor.

EARLIER WORK ON COBALT.

$(O = 16.)$

			Atomic Weight.
1826.	Rothoff	$CoO : 2\ AgCl.$	58.50
1857.	Schneider	From cobaltous oxalate	60.00
1858.	Marignac	$CoSO_4 : CoO$	58.76
1858.	"	$CoCl_2 : 2\ Ag$	58.85
1860.	Dumas	$CoCl_2 : 2\ Ag$	59.09
1863.	Russell	$CoO : Co$	58.74
1867.	"	$Co : H_2$ (measured)	59.08

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* Smithsonian Miscellaneous Collections, Constants of Nature, Part V. p. 291.

			Atomic Weight.
1866.	Sommaruga	$Co_2(NH_3)_{10}Cl_6 : 2\ Co$	59.95
1867.	Winkler	$3\ Co : 2\ Au$	59.42
1868.	Weselsky	From complex cyanides	59.13
1871.	Lee (under W. Gibbs)	" " "	59.20
1871.	" " "	$Co_2(NH_3)_{10}Cl_6 : 2\ Co$	59.16
1886.	Zimmermann	$CoO : Co$	58.89
1889.	Winkler.		
1891.	Remmler	$CoO : Co$	58.80
1892.	Schützenberger	$CoO : Co$	60.12
1893.	Winkler	$Co : 2\ Ag : 2\ AgCl$	59.82
1894.	"	$Co : I_2$	59.52
1895.	Hempel and Thiele	$CoO : Co$	58.99
1895.	" "	$Co : Cl_2$	58.78
1895.	" "	$Co : 2\ AgCl$	58.91

From these absurdly varying results, Clarke * computes the value 58.932 as the most probable atomic weight, while Seubert † selects 59.6, and Ostwald ‡ 59.0, as the true value. Of course, many of the figures above may be thrown out at once; but the evidence which remains after this first elimination is still too vague for anything like scientific certainty. It is not the purpose of the present work to discuss the accuracy of these bygone investigations; for such discussions are apt to be unconvincing. Inattention to a single matter of detail may easily overthrow all the value of quantitative labor; a post-mortem examination is not always able to detect the more subtle poisons. Our object is rather to accumulate a mass of data which we thoroughly understand, and then to interpret these data with regard to the probable chemical errors which may have crept into them. The present paper is only the first one of an investigation which we hope to continue until we have solved the problem.

The advantages to be gained by a simultaneous investigation of nickel and cobalt are obvious. Although the similarity of the two metals is usually overrated, it is still convenient to consider them together. Evidently much time may be saved in the preparation of materials if two similar researches are conducted side by side; and evidently the experience gained in one may be immediately helpful in the other. Fortunately, cobalt, like nickel, yields a bromide which is readily obtained anhydrous

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* *Loc. cit.*
† Zeit. Anorg. Chem., XIII. 229.
‡ Lehrbuch, Vol. I. p. 79.

in a state of great purity, and this metal therefore joins the ranks of those elements whose atomic weights may be determined by reference to silver through the most satisfactory of all processes of precipitation.

THE PREPARATION AND PROPERTIES OF COBALTOUS BROMIDE.

All the cobaltous bromide used in this research was prepared by passing bromine vapor over hot spongy cobalt. The sublimation of the salt is much less troublesome than that of the corresponding salt of nickel. The bright green anhydrous crystals of cobaltous bromide are very much less easily decomposed than the brown nickel compound by water or oxygen at a high temperature, in spite of the fact that cobaltous
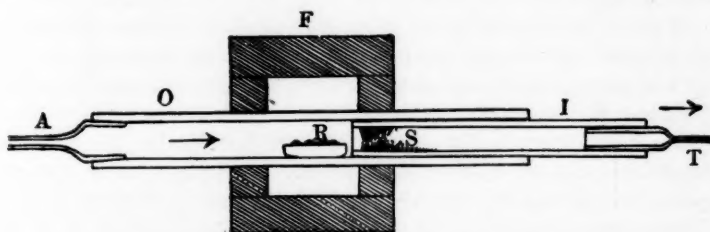

FIG. 1. SECTION OF APPARATUS FOR SUBLIMATION.

A = glass tube for admitting bromine vapor.   O = outer porcelain tube.   I = inner porcelain tube.   T = glass outlet tube.   F = perforated Fletcher furnace. R = boat containing cobalt.   S = Sublimed bromide.

bromide is very much the more hygroscopic and soluble in water when cold. In no case was a trace of an oxide of cobalt found among the crystals of bromide used for the analyses.

The first experiments were carried on in a hard glass tube heated by a "combustion" furnace, but as the high heat necessary to volatilize cobalt bromide played sad havoc with the glass, porcelain tubes, heated by means of a perforated Fletcher furnace,* were substituted. The arrangement was similar to that used in the research upon nickel. Into one end of a large porcelain tube (of which the internal diameter was 28 millimeters) was ground a glass connector fused to the apparatus for supplying a mixture of bromine vapor, hydrobromic acid, and nitrogen ; while inside of the other end was "telescoped" a closely fitting smaller porcelain tube designed to serve as the receiver of the sublimed material.

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* These Proceedings, XXXII. 63.

The boat containing the cobalt was of course placed in the hottest part of the furnace, and the open end of the inner tube was adjusted just beyond this point.   At first, the glaze of the receiver tube was attacked by the hot bromine and bromides, and the first sample of sublimate was found to be contaminated by the decomposition products of the glaze. Later the porcelain became covered with a brilliant-colored coating of a cobalt glaze which seemed to be permanent.   The sublimate used in the analyses was taken more especially from the central portions of the sub-limed masses, so that even if a small amount of alkali had been extracted from the porcelain it must have remained clinging to the walls of the tube.   All the sublimates excepting the very first gave a wholly clear aqueous solution.

As has been already stated, anhydrous cobaltous bromide thus pre-pared consists of brilliant green crystalline plates, which quickly absorb water from the air to form the pink hydrated salt, and dissolve with great ease in cold water.

The specific gravity of anhydrous cobaltous bromide being unknown, the following experiments were made to determine it. (a). 2.0915 grams of the salt which had been dried at about 200° displaced 0.3285 gram of kerosene (dried over soda and redistilled) at 25°. (b). 1.3965 grams of the salt displaced 0.2186 gram of kerosene.   The kerosene, which was used in this case because cobaltous bromide was found to be slightly soluble in toluol, had at 25° a specific gravity of 0.7698 referred to water at 4°.   Hence we have for the specific gravity sought, (a) 4.901, (b) 4.917.   The mean of these two values is 4.909.

Since brass weights were employed, in order to correct the weights of cobaltous bromide found in air during the subsequent accurate analyses to that which would have been observed in a vacuum, 0.00010 gram should be added for each gram of this material.   In the same way 0.000045 gram must be added to every apparent gram of argentic bro-mide, and 0.000031 gram must be subtracted from every apparent gram of silver.   These corrections are all applied below.

The balance used in this research was the one used in those upon copper, barium, strontium, zinc, and nickel : it needs no further de-scription.   The weights were of brass, gold plated; they were stan-dardized with great care, and were used for no other work.

PURIFICATION OF MATERIALS.

Cobalt. — The doubt which has been thrown on the elementary char-acter of cobalt by several experimenters led us to the application of un-

usual care in preparing the material used in this investigation. Pure cobalt was prepared by two entirely different methods; and a third sample was purified by both methods. The agreement of the results obtained from all of these samples leaves no doubt as to the uniformity of the material used.

In the first place about three hundred grams of commercial cobalt chloride were dissolved in a litre of water. The removal of the copper group as sulphides was of course the first step; but on account of the difficulty of filtering out small quantities of these sulphides, the solution was not acidified before passing in sulphuretted hydrogen. In this way enough cobalt sulphide was precipitated to sweep the solution free from small amounts of a precipitate which could not be removed by filtration. After long standing the supernatant liquid was decanted through a filter, and, as the precipitate was found to contain copper, the solution was again fractionated with sulphuretted hydrogen. The sulphides from this precipitation gave no test for copper, hence it is fair to conclude that the filtrate was free from this metal. After the addition of a large amount of hydrochloric acid to this filtrate, and then ammonic hydrate until the mixture was strongly alkaline, pure sulphuretted hydrogen in excess was passed into the solution. The precipitated sulphides were washed several times with water, and then digested with cold dilute hydrochloric acid. The precipitate was then washed free from iron by decantation. As the succeeding purification by means of potassic nitrite was in itself a separation from many other metals as well as from nickel, it was not thought necessary to reprecipitate the cobalt sulphide at this stage. Accordingly the precipitate was dissolved in aqua regia, and after dilution and filtration the solution was evaporated until the greater part of the excess of acid was driven off. Sodic hydrate was then added to the diluted solution in slight excess, and subsequently a large amount of acetic acid. Upon the addition of potassic nitrite all the cobalt was precipitated as the crystalline yellow double nitrite of potassium and cobalt. This precipitate was washed by decantation several times, and after its solution in strong hot hydrochloric acid the precipitation was repeated. The reagents used in this purification were especially tested for calcium; for only in the absence of calcium is the separation of cobalt from nickel complete by this method. The efficiency of the separation is shown by the fact that the filtrate from the first precipitation was distinctly green, owing to the nickel salts present, while the filtrate from the second precipitation after evaporation to small volume merely turned faintly brown on the addition of ammonic sulphide. The double nitrite was again dis-

solved in hydrochloric acid, and the cobalt was partially freed from alkalis by precipitation as sulphide. The sulphide was then treated with an excess of nitric acid and was heated upon the steam-bath until the resulting cobalt nitrate was free from every trace of chlorine.

In order to free the cobalt from alkalis it was next to be precipitated by electrolysis; and at first we hoped to convert the electrolytic film directly into bromide. However, on passing a galvanic current through the ammoniacal nitrate, an oxy-amine was precipitated in such quantities as to render the use of this electrolyte impossible. Experiments were then made with the ammoniacal sulphate in order to find the conditions most favorable for the deposition of a bright coherent film. The negative electrode was a platinum dish, the positive electrode a flat spiral of platinum wire. The first attempts, which were made in a dish holding 250 cubic centimeters and having an area of 150 square centimeters, with currents from 0.3 to 0.7 ampere, and with solutions of widely varying strengths, resulted in the deposition of dull black films. With a current strength of more than one ampere, however, the film was always compara tively bright. It was found impracticable to use this film directly for conversion into bromide on account of the difficulty of stripping the film from the dish. Accordingly, after being thoroughly washed, it was dissolved in the dish by nitric acid which had been distilled with a platinum condenser; and when the excess of acid had been driven off by evaporation, a slight excess of pure ammonia (made by distilling ordinary pure ammonia into pure water contained in a platinum dish) was added. The resulting green precipitate was washed several times by decantation with the purest water, filtered on a washed filter, dried in a steam oven and finally, after separation from the filter paper, ignited to the black oxide in a platinum crucible. During the ignition this crucible was contained in a porcelain crucible which was heated by an alcohol lamp. Pure metallic cobalt was prepared from this oxide by reduction in a stream of ammonia gas, generated in an apparatus composed entirely of glass and dried by passage over stick-soda. Metallic cobalt is thus obtained in a spongy form, well adapted for its following treatment with bromine, and certainly free from all such impurities as alkalis and silica. The cobalt bromide, prepared from this metal in the manner already described, was labelled No. I.

The second method of preparing pure cobalt was by precipitation as one of its amines. The purpureo-chloride seemed best suited for the present purpose, both on account of the ease with which it can be prepared and because of its comparative insolubility in cold ammoniacal or

acid solutions. At first this compound was made by passing a current of air for some time through a solution containing cobaltous chloride, ammonic chloride, and ammonia. A considerable quantity of purpureochloride was formed by this process; and from the solution, by acidification with hydrochloric acid and cooling, fully as much more was obtained. Later another method, capable of giving a much larger yield, was used. Into the strongly ammoniacal solution bromine was dropped slowly. A heavy precipitate resulted, and the solution upon acidification and cooling as above yielded the greater part of the cobalt it contained. Several lots of amines which had been prepared in one or the other of these ways were mixed and dissolved in hot ammonia. After filtering the solution was acidified with hydrochloric acid, with the result that on cooling nearly all the cobalt was reprecipitated. The precipitate was washed by decantation with cold dilute hydrochloric acid, and the whole process of recrystallization repeated. This time the precipitate was collected on a pure filter and dried. After separation from the filter paper it was converted into the sulphates of cobalt and ammonium by heating on a sand bath with sulphuric acid until all chlorine or hydrochloric acid fumes had ceased to come off. From the solution of these sulphates metallic cobalt was prepared by electrolysis, solution in nitric acid, precipitation as hydrate, and reduction, in the manner already described. This preparation was designated as Sample II.

For the final analyses the cobalt was purified by a combination of all the before mentioned methods. The carefully purified cobaltous nitrate from Sample I. was converted into a cobaltamine compound, and this salt was six times recrystallized by solution in ammonia and precipitation with hydrochloric acid. Each time the precipitate was washed twice by decantation with hydrochloric acid, and after the second, fourth, and sixth dissolving the ammoniacal solution was filtered. The final precipitate was converted into spongy metallic cobalt in the usual manner. After sublimation part of the bromide prepared from this cobalt was resublimed to see if this process had any influence on the salt. That which had been resublimed was labelled IV., the other III. The apparatus used for the sublimation has been already described (page 117).

Silver was prepared with great care, according to a method similar to that described in previous papers from this Laboratory.* The only improvement introduced was the removal by means of nitric acid of the surface of the buttons, which had been fused in a vacuum upon a boat of

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* These Proceedings, XXXII. 62.

lime.   This treatment is of course more thorough and satisfactory than
Stas's method of digesting them with hydrochloric acid.   The silver was
subsequently treated with ammonia, thoroughly washed with water, and
dried in a desiccator over soda lime.   One large piece was rolled out be-
tween clean steel rollers; and the foil, after having been cut into small
strips, was cleansed as above described.   These fragments made it pos-
sible to weigh out any desired amount of the metal.

Bromine was prepared in common with Mr. Cushman.   For the
method used the paper upon nickel should be consulted.   Much ex-
perience has led to the conclusion that the method there described is the
most satisfactory and convenient means of obtaining pure bromine, since
it eliminates organic as well as inorganic impurities.   In order to test
the purity of the bromine and silver, 2.18679 grams of silver (in vacuum)
were dissolved in pure nitric acid and precipitated with a slight excess of
ammonic bromide which had been prepared by running the bromine in
question into pure ammonia.   The silver bromide was collected on a
Gooch crucible and afterwards fused in a porcelain crucible.   The fused
bromide weighed 3.80679 in vacuum, whence the ratio of silver bromide to
silver is 100.000 : 57.444.   Mr. Cushman, experimenting upon the same
sample of bromine, obtained the result 57.445; and since Stas's result
was identical with these, there can be no doubt of the purity of our silver
and bromine.

The sulphuric acid used in the drying towers was boiled for some time
in order to increase its efficiency and to free it from volatile impurities.
The phosphoric oxide was proved free from volatile compounds of phos-
phorus by passing a current of air over a considerable quantity of this
substance into aqua regia for several hours.   The aqua regia was sub-
sequently found to contain no phosphorus.   Distilled water was pre-
pared with all the usual precautions necessary to free it from organic
and non-volatile impurities, as well as from ammonia; nitric and hydro-
bromic acids were purified by repeated distillation with a platinum con-
denser; great care was taken to exclude dust, as well as the products of
the combustion of illuminating gas, from the substances under treatment;
platinum vessels were employed wherever it was possible to employ
them; and many other precautions, often essential in order to prevent
the complicated processes from introducing as much impurity as they
removed, were applied.   Alkali metals and silica, it will be seen, were
among the impurities avoided as much as possible.   For several pieces
of platinum ware and other apparatus we are indebted to the Cyrus M.
Warren Fund for research in Harvard University.

THE METHOD OF ANALYSIS.

The most insidious of all impurities in accurate quantitative work is water. Its insidiousness is due to the difficulty of detecting it in small amounts, as well as to its invariable occurrence in the atmosphere and its common use as a solvent and medium for crystallization. Our first analytical problem, in this case just as in the case of nickel, was to weigh the salt to be analyzed in such a fashion as to exclude this ever watchful enemy. The fact that cobaltous bromide is less easily decomposed at high temperatures than is nickelous bromide, tended to make our present problem the easier of the two; but the much greater hygroscopicity of the cobalt salt had the opposite tendency. The apparatus so useful in the cases of magnesium,* zinc, and nickel, proved to be equally serviceable here; cobaltous bromide, after being ignited in a stream of mixed
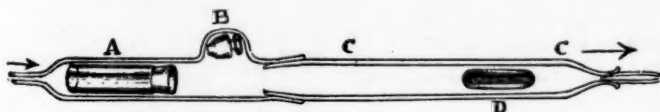

FIG. 2. BOTTLING APPARATUS, HORIZONTAL SECTION.

A = weighing bottle. B = stopper of bottle. CC = hard glass tube.
D = Platinum boat containing cobaltous bromide.

nitrogen and hydrobromic acid, cooled in dry nitrogen, and bottled automatically in dry air, may be weighed with perfect certainty. The bottling apparatus has been described so often that further details are unnecessary here; but the apparatus for supplying the desired gases has not yet been explained in all the complication of its present form.

In the first place, nitrogen was prepared by passing air through strong ammonia water, and then over red hot copper. The nitrogen, after passing through several flasks of sulphuric acid, to remove the excess of ammonia, was conducted into column 1 (see Figure 3), containing beads soaked with silver nitrate, in order to free the gas from the possible admixture of sulphur compounds taken from the rubber connections which were used in the apparatus for making nitrogen. In the columns numbered 2 were beads drenched with strong sulphuric acid, which thoroughly dried the nitrogen. With stop-cock 12 open, the nitrogen

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* Richards and Parker, These Proceedings, XXXII. 59. Richards and Cushman (on Nickel), *ante*, p. 95.

passed over phosphoric anhydride in tube 11 directly into the bottling tube. With stop-cock 12 closed and 4 open, the nitrogen of necessity bubbled through bromine in the small flask 5 ; beyond this flask, if stop-cock 9 were open, the gases passed directly over phosphoric anhydride in 10 to the cobalt bromide ; if stop-cock 9 were closed, the nitrogen and bromine together passed into the flask 6, containing hydrobromic acid and red phosphorus, thence into the U tube 7, containing beads moistened with hydrobromic acid and red phosphorus, thence over anhydrous
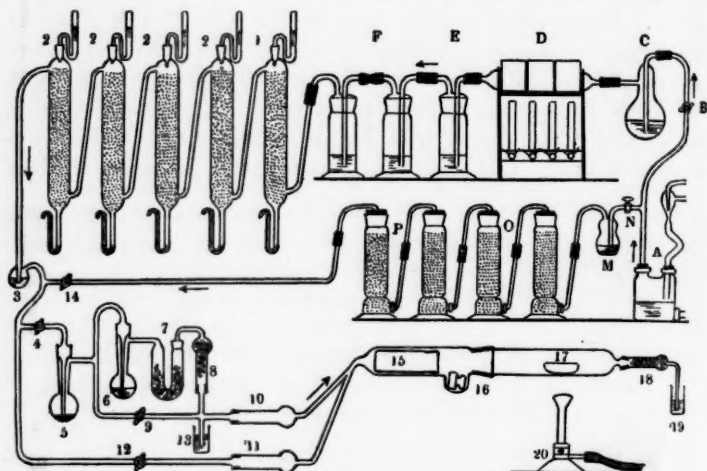

FIG. 3. APPARATUS FOR IGNITING COBALTOUS BROMIDE IN ANY DESIRED MIXTURE OF GASES.

The use of rubber was confined to the first part of this train, where it could do no harm. (A B C D E F and A M N O P).

calcic bromide in the tube 8 to remove the water taken from the hydrobromic acid, and finally over phosphoric anhydride in 10 to the bromide of cobalt. Dry air was prepared by passing a current of air through several columns of beads (OP in the figure) moistened with sulphuric acid, and then into the apparatus through the stop-cock 14. The pressure of the sulphuric acid in the bulb 3 prevented any air from backing up into the sulphuric acid columns delivering nitrogen. In order to prevent the slightest admixture of hydrobromic acid with the dry air used to wash out the apparatus at the conclusion of the operation, a slight excess of pressure was always maintained within the apparatus. This excess of pressure was so regulated as to cause a part of the pure

air to go backwards through tube 10 (stop-cocks 4 and 9 being closed), and to bubble through the sulphuric acid kept in the vessel labelled 13. The tube and vessel served as a safety valve and pressure gauge throughout the whole operation. The ground joints were kept tight by means of syrupy phosphoric acid.

To the right hand end of the complex apparatus here described was fused the automatic bottling apparatus, as indicated in Figure 3. By means of this arrangement the cobaltous bromide could be thoroughly dried and enclosed in a suitable bottle for weighing without a moment's exposure to the moist air of the room. In one case, where a platinum boat containing several grams of the salt was reheated and rebottled after weighing, the loss in weight was found to be only 0.11 milligram, an amount not greater than the probable loss by sublimation at the high temperature (400°) employed in the ignition. Hence the apparatus evidently answers its purpose well.

The preliminary analyses were so much easier to make than those described in the preceding paper,— because of the ready solubility of the salt used and its invariable freedom from the oxide whose presence had caused trouble at first in the work upon nickel, — that only three were deemed necessary.

The method of procedure may be easily gathered from previous descriptions. The bromides of cobalt and silver were each weighed, as in the case of the nickel, and from the assumed molecular weight of argentic bromide 187.885 that of cobaltous bromide was calculated.

From the value for the atomic weight of cobalt obtained from this preliminary series, the approximate proportion of silver necessary for the complete decomposition of a given weight of cobaltous bromide was calculated; and in the succeeding analyses the proper amount of silver was weighed out in each case. After the silver had been dissolved with precautions to prevent loss during the process, and after the solutions of cobaltous bromide and argentic nitrate had been much diluted, the precipitation was effected in a roomy, glass-stoppered Erdenmeyer flask; and the mixture was very thoroughly shaken and allowed to stand. In three experiments, Nos. 4, 6, and 7, the precipitation was completed by titrating backward and forward with centinormal argentic nitrate and hydrobromic acid solution, until the precise point was found; * while in Nos. 8, 9, 11, 12, and 13 the nephelometer was used to determine the end-point. † Of course the work was done in yellow light or in darkness,

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* These Proceedings, XXVIII. 24; XXX. 384.   † Ibid., XXX. 385.

and great care was taken to prevent the loss of any of the precipitate. The results of this determination of the amount of silver required to precipitate the bromine in cobaltous bromide are given in the table headed " Third Series " below.   The " Second Series " of results was obtained by weighing the argentic bromide precipitated in the manner just described.   Before filtering, a slight excess of argentic nitrate was

THE ATOMIC WEIGHT OF COBALT.

$O = 16.000$; $Ag = 107.93$.

FIRST SERIES (PRELIMINARY). $2\ AgBr : CoBr_2$.

Number of Analysis.	Sample of $CoBr_2$.	Weight of Cobaltous Bromide in Vacuum.	Weight of Argentic Bromide in Vacuum.	Atomic Weight of Cobalt.
1	I.	2.25295	3.86818	58.950
2	I.	2.88763	4.95732	58.975
3	I.	1.88806	3.24056	59.026
			Average	58.984

SECOND SERIES. $2\ AgBr : CoBr_2$.

Number of Analysis.	Sample of $CoBr_2$.	Weight of Cobaltous Bromide in Vacuum.	Weight of Argentic Bromide in Vacuum.	Atomic Weight of Cobalt.
4	I.	1.33564	2.29296	58.975
6	I.	2.58129	4.43095	58.998
7	I.	2.84382	4.88135	59.009
8	I.	1.83722	3.15368	59.000
9	I.	2.68584	4.61046	58.996
10	II.	3.18990	5.47607	58.982
11	II.	2.88914	4.95943	58.997
12	III.	2.32840	3.99706	58.987
13	IV.	1.91703	3.29053	59.010
			Average	58.995

THIRD SERIES.   2 Ag : CoBr₂.

Number of Analysis.	Sample of CoBr₃.	Weight of Cobaltous Bromide in Vacuum.	Weight of Silver in Vacuum.	Atomic Weight of Cobalt.
4	I.	1.33564	1.31702	59.002
6	I.	2.58129	2.54585	58.955
7	I.	2.84382	2.80449	58.977
8	I.	1.83722	1.81170	58.991
9	I.	2.68584	2.64879	58.969
11	II.	2.88914	2.84891	58.998
12	III.	2.32840	2.29593	59.003
13	IV.	1.91703	1.89033	58.999
			Average	58.987
			Average of Series II. and III. . . .	58.991

added, and after long agitation the precipitate was collected as usual upon the Gooch crucible. The shreds of displaced asbestos were collected and weighed; and from the total was subtracted the small amount (if any) of argentic bromide resulting from hydrobromic acid added in titration. One experiment (No. 5), in which the cobaltous bromide contained a few visible chips of porcelain from the tube used in subliming, was rejected; and in one (No. 10) the weight of the silver was not determined.

As usual in cases of this sort, we may obtain a useful check upon the accuracy of these results by comparing the amount of silver required with the amount of argentic bromide formed. Thus, in all these experiments taken together 18.16302 grams of silver yielded 31.61642 grams of argentic bromide,— a ratio of 57.448 to 100.000. If we take only the last five experiments (8, 9, 11, 12, and 13) which were the most carefully made, the ratio becomes 57.446 : 100.000, while Stas's result is 57.445. The value of this comparison has been pointed out in the previous paper on nickel.

A still more important consideration is the identity of the results obtained from the various samples. The average of all the results of each of the four preparations is given below, — the first average comprehend-

ing ten results, the second three, and the third, and fourth each two results.

Sample I.	58.987
Sample II.	58.992
Sample III.	58.995
Sample IV.	59.004

In this case, as in the case of nickel, a slight rise in the atomic weight is to be observed with the increasing purity of the materials. Although larger here than before, the rise cannot be considered greater than the probable experimental error,— especially since one or two of the individual results obtained from Sample I. were slightly greater than any obtained from Sample IV. We must therefore conclude that, if "gnomium" exists, it must have an atomic weight about equal to that of nickel and cobalt, and hence that the wide variations to be observed in the results of other experimenters cannot be considered a valid argument in favor of the late Professor Krüss's doubtful discovery.

According to the present investigation, then, the atomic weight of cobalt seems to be very close to 59. Upon comparing this result with the earlier ones of other experimenters, we see that this result is as much in accord with their general verdict as almost any other would be. In other words, the values are so various in magnitude that no satisfactory conclusion can be drawn from them. It is worth noticing that one of the results obtained by Thiele, under Professor Hempel's direction, agrees exactly with ours, however.

Our work thus has this outcome, at its present stage: —

If Oxygen = 16.000,   Cobalt = 58.99.
If Oxygen = 15.88,   Cobalt = 58.55.

CAMBRIDGE, MASS., June, 1897.